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PERFORMANCE MEASUREMENTS OF THE INJECTION LASER SYSTEM CONFIGURED FOR PICOSECOND SCALE ADVANCED RADIOGRAPHIC CAPABILITY

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Abstract. We have characterized the Advanced Radiographic Capability injection laser system and demonstrated that it meets performance requirements for upcoming National Ignition Facility fusion experiments. Pulse compression was achieved with a scaled down replica of the meter-scale grating ARC compressor and sub-ps pulse duration was demonstrated at the Joule-level.

1. Introduction

Dynamic x-ray radiography of Inertial Confinement Fusion (ICF) implosions is a core requirement for diagnosing key experimental parameters in the National Ignition Campaign. The Advanced Radiographic Capability (ARC) upgrade project at the National Ignition Facility (NIF) is designed to deliver short-pulse kilo-Joule laser pulses for X-ray backlighting of NIF fusion capsules. When complete, eight Petawatt-class high-intensity beamlines with controllable delays will add the capability to record the dynamics of fuel compression and fusion ignition in a multi-frame X-ray “motion-picture”[1, 2]. ARC will also support a variety of other high energy density experiments and fast igniter studies on NIF. Full scale fast ignition on NIF will require high-energy (tens of kJ), short pulse duration (~10 ps), and small focal spot size (tens of microns).

2. ARC architecture

ARC is a Petawatt-class, chirped pulse amplification (CPA) system implementing eight meter-scale four-grating compressors to deliver compressed pulses just before focusing into the NIF target chamber. ARC will operate in a split beam configuration, dividing each NIF aperture into two subapertures that fit on pairs of side-by-side, 91 cm wide, compressor gratings. This split-beam architecture produces eight, high-intensity, short pulses from a quad of NIF beamlines. The short pulse is generated in a mode-locked fiber oscillator, ensuring stability and robust operation in a compact geometry[3]. Pulses are stretched for CPA in a chirped-fiber-Bragg grating (CFBG), specially designed as the conjugate of the calculated dispersion of the overall laser system. After further amplification the beam is split into two, and launched into two small bulk grating pre-compressors, functioning as pulse width controllers (PWC). By adjusting the group velocity dispersion of each pulse, these PWCs will control the temporal pulse width at the final ARC compressor output from the sub-ps transform limit to 50 ps. The pulses are then routed by a transport fiber and amplified by a Yb-doped fiber up to 1 microJoule just prior to injection into bulk Nd:Glass regenerative amplifiers. To compensate for gain-narrowing, we added a birefringent, gain-flattening filter to the regen cavity, extending the bandwidth from 2.2 nm to 4.5 nm at the output. The two regen outputs are spatially shaped, apodized and combined as two ARC sub-apertures whose outer perimeter matches a NIF beam at the input of the 4-pass rod amplifier. The shaping is designed to pre-compensate the spatial gain profiles in the NIF rod and slab amplifiers to produce a pair of rectangular, flat-top, near-field profiles at the NIF amplifier chain output. The regen outputs are then combined and shaped into a pair of subapertures in a Split Beam Injection (SBI) module. The combined shaped beam is then further amplified in a 4-pass Nd:Glass rod amplifier, producing up to 6 Joules in a spatial format tailored for direct injection into the NIF main amplifiers. The main amplifiers will amplify each individual subaperture to ~1 kJ (dependent on pulse duration). Two vacuum vessels containing 4 compressors each compress the pulses; the output pulse duration is dependent on the PWC setting. Space constraints in the NIF target bay required a compact folded compressor design. There are actually four pairs of 4 grating compressors: one grating in the pair is illuminated by one ARC sub-aperture and the second grating of the pair is illuminated by the other sub-aperture. Each grating in the pair has slightly different groove densities to reduce crosstalk between the subaperture beams. Each of the compressors employs four different 91cm x 45 cm multi-layer dielectric diffraction gratings, made by LLNL[4].

Four major contributions to group velocity dispersion need to be carefully balanced: Material dispersion of several tens of meters of glass, CFBG, PWC, and the compressor (Fig. 1 left). Since the system does not allow adjustment of the dispersion among different NIF apertures, alignment of the 8 ARC compressors has to be performed such that the overall residual group delays are less than 1 ps across all subapertures to meet specifications. An RF phase-shifting technique[5] will be used to precisely measure the group delay of each individual subsystem and to match the dispersion characteristics of each individual compressor.

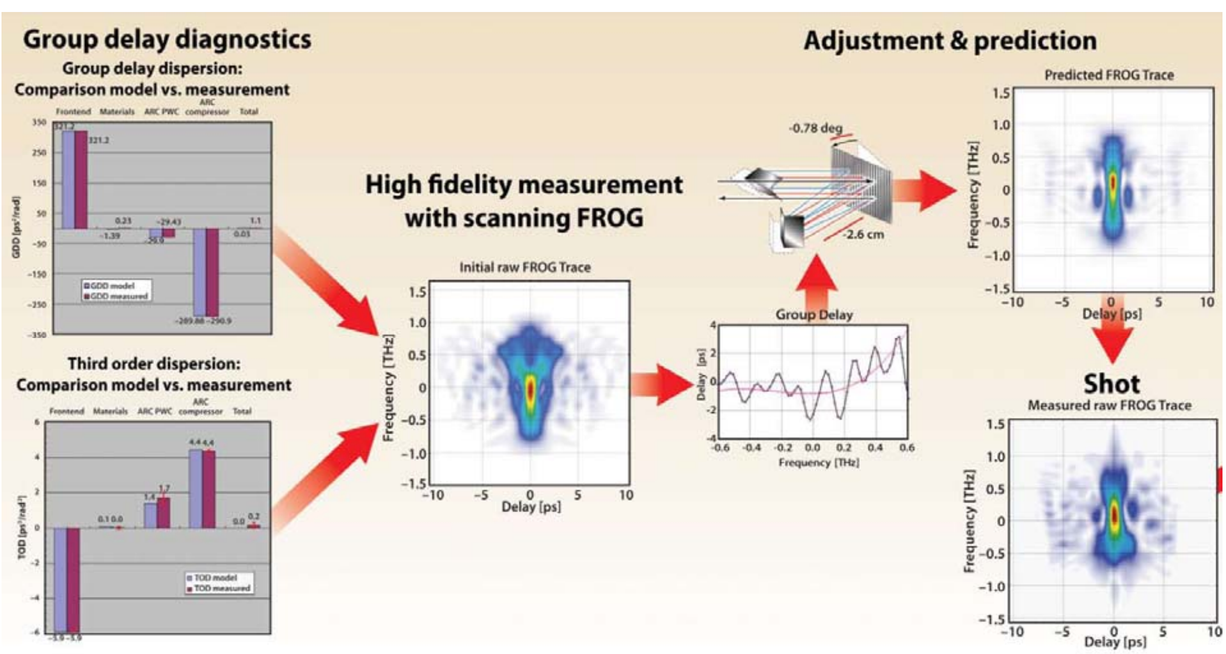

Figure 1: Strategy for balancing dispersion on the ARC testbed: offline GD-measurements are compared with the model, and dispersion in the full system is compensated to better than 1 ps^2/rad. A high fidelity scanning FROG reveals residual GD, and by minimizing RMS GD deviations adjustments are made to the PWC accordingly.

3. ARC frontend test facility

The performance of ARC relies critically on the front-end performance and the dispersion pre-compensation in the system. We have built and qualified the ARC front-end prototype (up to the 4-pass Joule level amplifier) in an offline facility. We use this test facility to demonstrate dispersion balance, measure temporal fidelity, and characterize the near- and far-field spatial profiles for the compressed ARC front end. We also use this facility to provide real data for our propagation and energetics models that predict overall performance of the ARC system. In order to test compressed pulses, we constructed a scaled down compressor designed with the same calculated dispersion values to demonstrate our dispersion management scheme. After installation, we measured the group delay (GD) dispersion of the compressor using the phase shifting technique described in [6]. Earlier measured GD-data of the fiber front was used to design the PWC. We also test various temporal diagnostics on this test facility that will be used for recording shot data at the ARC output. The temporal diagnostics include an ultra low-energy (picoJoule), scanning cross-correlator, a single-shot FROG (frequency resolved optical gating) device allowing detection of pulses up to 5 ps in duration, and a homebuilt multi-shot scanning FROG with ultra-wide temporal window (several tens of ps and true ~1:400 dynamic range). We also record for each shot a high resolution spectrum to validate our results.

4. Results

Using the birefringent intracavity filter in the regen, the spectral width of the laser output was optimized. Gain narrowing in the pre-amplifier module using a LHG-8 rod is compensated by broadening and shifting the regen spectrum to the blue. The spectrum was centered at 1052.6 nm and

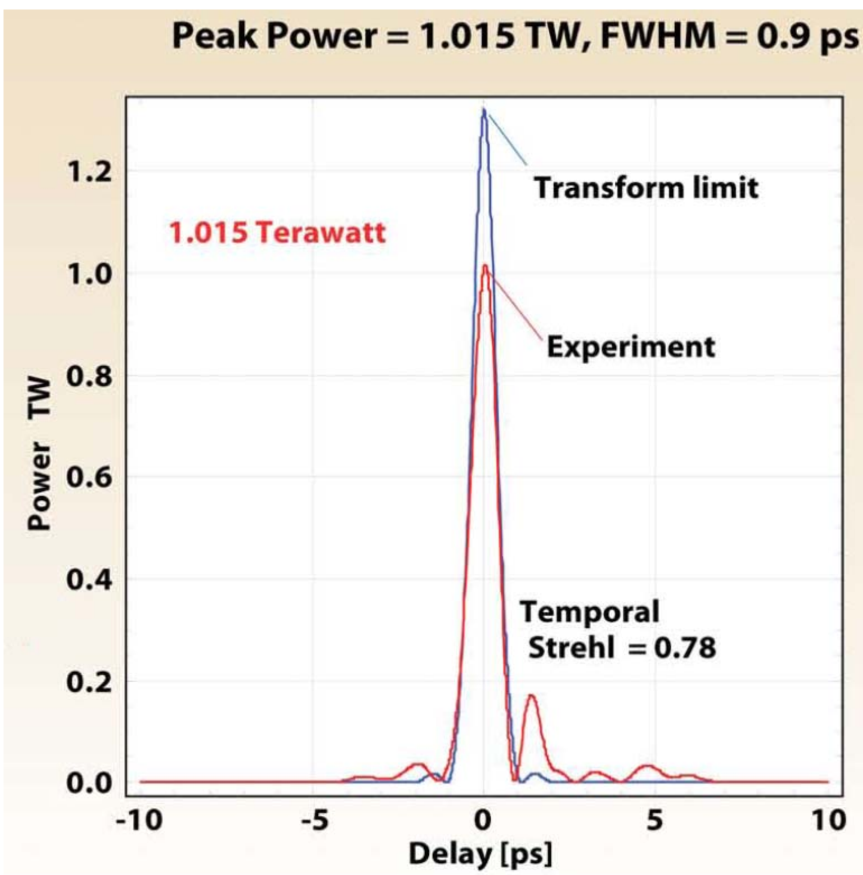

Figure 2: Power measurement derived from energy and single shot FROG diagnostics at the compressor output in the ARC Injection Laser Test Facility.

broadened up to 4.5 nm. Figure 1 shows our strategy for balancing dispersion in the ARC injection laser testbed: We set the PWC grating angle of incidence, AOI, and slant distance to the nominal values predicted by our group delay diagnostic measurements and dispersion balance model. Small adjustments to the PWC and compressor alignment are made to be in good agreement with modeled dispersion values. The total residual group delay derived from the group delay measurements is less than 1 ps^2/rad. Then we measured the compressor output pulse width with a single-shot autocorrelator while optimizing the PWC slant distance for the shortest autocorrelation. A change of ~2mm in slant distance from the model prediction was necessary to produce the shortest pulse on the autocorrelator. Next we made a high dynamic multishot FROG measurement, and performed a high resolution, precision FROG analysis based on principal components gerneralized projections[7] yielding E(t, λ). We mimimized the RMS deviations of the GD across the spectrum using the angle of incidence and slant distance of an analytic Treacy formalism as parameters (see Fig.1).. The obtained values were applied to the PWC and the measurement repeated. Fig. 1 shows also the predicted FROG trace with the change in dispersion based on the Treacy model for the PWC. After changing angle of incidence and slant distance of the PWC according to the analysis a nearly transform limited pulse duration of 814 fs was measured with scanning FROG. Then the system was configured for Joule-level amplification and the diagnostics configured for single shot. We fired a shot at 1.3 J and recorded the temporal pulse characteristics with single shot FROG. The trace is shown on the right side in Fig. 1. Figure 2 shows the pulse measurement derived from energy and temporal diagnostics, yielding 1.02 TW in peak power. The slight increase in pulse width from 814 fs to 898 fs is expected and attributed to gain narrowing in the 4-pass Nd:Glass rod amplifier. The remaining small pre-pulse ~1.3 ps ahead of the main pulse is attributed to the group delay ripples in the CFBG and does not affect the overall performance of ARC.

Acknowledgments
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